

Final Report for AOARD Grant FA2386-10-1-4116
“*The Development and Use of Expertise in Complex Environments*”

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Abstract:

This project set out to understand the source of ‘expert intuition’ in complex decision-making. Such intuitive decisions are characterized as rapid, efficient and highly robust and they are based on a subconscious or preconscious processing of information. It has been shown in earlier studies that cognitive function, particularly working memory and associated skills, is significantly impaired under stressful circumstances: we begin to lose awareness of our circumstances, confusion sets in and it becomes difficult to reorient ourselves and regain control of the situation. This is not always the case for well trained ‘experts’, with sufficient experience their map of the environment does not stem from conscious thought processes, what Daniel Kahneman calls **System 2** processes, instead experts are able to reason using a very efficient, sparse and automatic representations of their environment, this is what Kahneman calls a **System 1** process. While this research used a board game and massive artificial neural networks to simulate a System 1 process, the resultant cognitive model that was developed during this grant tells us a great deal about the development of these skills including suggesting a method by which we can recognize when someone has become an ‘expert’ and how we might be able to facilitate this development. The principles developed during this research also provide a significant step on the path to innovative new techniques for the development of truly autonomous and adaptive Artificial Intelligence systems.

Introduction:

What makes an expert so good at what they do? Over the last 60 years it has proven to be notoriously difficult to extract an expert's knowledge and either use it to train others or to encode it into an Artificial Intelligence or any ‘expert system’. The necessary clues required to develop such systems were provided by Herbert Simon in the 50's and 60's when he suggested that the core of an expert's skill is based on their different (and better) perception of the task environment. However the expert is not consciously aware of where their improved skill comes from and so is often unable to tell researchers how it might be replicated, this is because such intuition does not occur at a conscious (i.e. reportable) level.

In order to try and understand the mechanisms by which this occurs I had to develop a new methodology that replicated the most important aspects of implicit perceptual

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learning, this is also known as 'perceptual expertise' or more specifically 'visual cognition'. This had never been done before in a task requiring decades for humans to master and the two neural networks that were developed, each containing a million neurons each, are unique to this project. The result of the learning process for these networks are what I have called 'perceptual templates', sparse representations of the task environment that can be used to guide visual search, suggest a small number of actions to take next and to do so in a robust, dynamical and ongoing fashion.

Experiment:

I collected the raw game data from two different sources, the expert data came from a database of 60,000 games I bought called the GoGod database. The novice games were collected using custom designed scripts that recorded games being played online by mid-ranked players. This data was then run through neural networks of the Kohonen 'Self-Organising Maps' (SoM) variety. In order to do this a novel interpretation of the problem was required: The move being played was held fixed while every 'context' in which that move was made was processed through the SoM. This was then repeated for every possible move, resulting in a large collection of contextual templates to be generated that provide mid-level representations of the perceptual contexts in which moves are made.

Results and Discussion:

The most significant outcomes from this work have been a neuro-cognitive model for the development of expertise and the precise quantification of the differences between experts and non-experts in their perceptual awareness of their environment.

These templates were then used as the basis of a new neuro-cognitive model that represents the early stages of complex decision-making without the conscious awareness of the expert. In this sense such cognitive processes are not influenced by the capacity restricted components of cognition and it is these capacity restricted components that are also significantly influenced by stress. Recent results from fMRI studies carried out by other research groups has shown that this progression from explicit or declarative types of knowledge, i.e. thinking that is susceptible to the influence of stress on conscious processing, can be measured as an activation in the Temporal Cortex of the brain.

Some of the significant properties of the cognitive model developed in this study include:

1. The model is an accumulator of visual evidence of an uncertain quality and reliability, in line with current thinking of human neural behaviour,
2. The perceptual information that is common between experts and non-experts can be very small, I found only 15% in common between the two, suggesting strong un-learning or re-learning is required for expertise to develop,
3. There are more commonalities between experts and non-experts when smaller amounts of information is involved, the more complex the information becomes the greater the difference between the two types,
4. There is greater complexity and variety in the use of the visual cues for experts than non-experts.
5. When learning has occurred there is a detectable change in brain wave patterns

This last point (5.) was work carried out by other researchers on this same topic but it

is a part of the model developed in this work.

Finding and activating these mechanisms is of primary importance in the rapid training and deployment of personnel into complex and stressful environments where superficial training fails but imbedded expertise comes to the fore. Further research should aim to explicitly study the relationship between the migration of perceptual cues and cognitive strategies from short term memory to long term memory, the number of cues that can be held in a single template in long term memory (i.e. its capacity), the complexity of the relationships between these cues and the ability of subjects to automatically access these memories in stressful situations when their short-term cognitive functions may be compromised. This will provide a clear connection between how complex such automatic processes can be and how long the training needs to be in order to activate such skills. Beyond this, such investigations should provide vital clues into the types, variety and quantity of signals personnel are able to integrate in order to perform automatically under stress so that more informative and useful information can be made available in critical situations.

But most importantly, what this study has shown is that an expert's mental picture of a complex task environment is critically informed by a sparse representation of that environment enabling them to quickly and automatically orientate themselves and generate rapid and robust decisions, even under significant stress loads. Understanding the boundaries of such abilities in specific tasks will be a rich and useful area for future research.

List of Publications:

Submitted

Harré, M. From Amateur to Professional: A Neuro-Cognitive Model of Categories and Expert Development (submitted to *Cognition*, May 2012).

Accepted

Harré, M., Bossomaier, T. & Snyder, A. The Perceptual Cues that Reshape Expert Reasoning (Accepted *Nature: Scientific Reports*, June 2012).

Bossomaier, T., Thiruvarduchelvan, V. & Harré, M. (2012) Seeing the Big Picture: Influence of Global Factors on Local Decisions. (Accepted: *International Journal on Advances in Software*)□

Harré, M. & Snyder, A. (2011). Intuitive Expertise and Perceptual Templates. *Minds and Machines*, December 14, p. 1-16 DOI 10.1007/s11023-011-9264-9.□

Bossomaier, T. & Harré, M. (2011). Global Context Influences Local Decisions. *Cognitive, 3rd Conference on Advanced Cognitive Technologies and Applications*.

Harré, M. & Snyder, A. (2011). Transitions in Learning About Your Opponent. *IEEE Conference on Intelligent Computing and Intelligent Systems*.□

Harré, M. & Snyder, A. (2011). Neural Networks for Opponent Modelling in Complex Contexts. *IEEE Conference on Intelligent Computing and Intelligent Systems*.□